Top Quark Mass Measurements with the CMS Detector

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XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects
April 24, 2013

Introduction

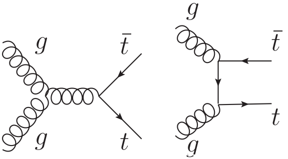
- Top quark is the heaviest among the observed particles.
- Precision measurement of top quark mass provides important constraints for EW-Sector.
- Top quarks are produced abundantly at the LHC, allowing precision measurements.
- Tevatron measured the top mass with high precision:

$$\boxed{m_t = 173.18 \pm 0.56(\text{stat.}) \pm 0.75(\text{syst.})\,\text{GeV}}$$

- Several CMS measurements with compatible precision.
- Experimentally, the top quark mass is measured as invariant mass of the top quark decay (b and W).
- Translation to top quark mass has uncertainties of $0.5 - 1\,\text{GeV}$.
- CMS introduces new analysis techniques to help reduce this uncertainty.

Top Pair Production and Detection

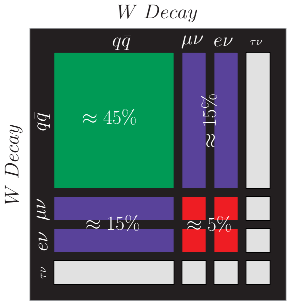
QCD top quark pair production at LHC:



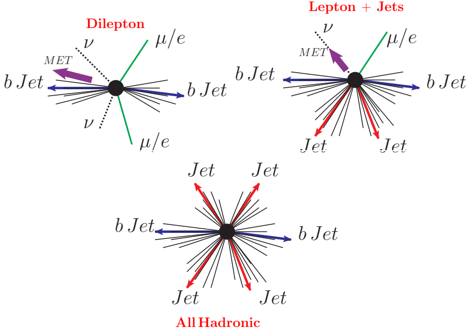
$$\sigma_{t\bar{t}} = 161.9 \pm 6.7\,\mathrm{pb} \text{ at } \sqrt{s} = 7\,\mathrm{TeV}$$ (arXiv:1208.2671)

$$\sigma_{t\bar{t}} = 227 \pm 15\,\mathrm{pb} \text{ at } \sqrt{s} = 8\,\mathrm{TeV}$$ (CMS PAS TOP-12-007)

$t \to W + b \sim 100\%$



Experimental Signature



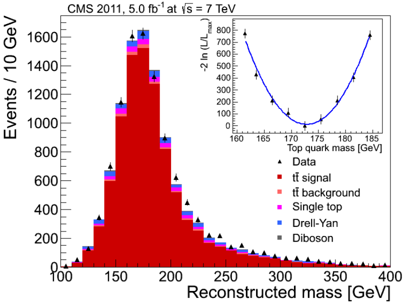
Dilepton Channel

Eur. Phys. J. C72 (2012) 2046

- Selection requires at least one btag jet.
- Main background: Drell-Yan (estimated from data).
- Kinematic properties are characterized by 24 parameters: 14 from measurements and 9 constrained(m_W, $m_t = m_{\bar{t}}$...).

  - Neutrino momentum is determined with an analytical method.
  - Analytical matrix weighting technique(AMWT): After solve many times per event the kinematic equations, a weight to each solution is assigned:

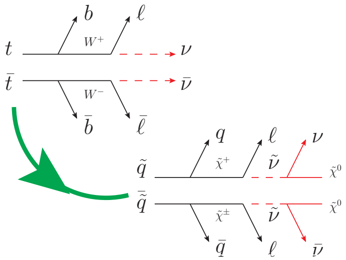
$$w = \left\{ \sum f(x_1) f(x_2) \right\} p(E^*_{\ell+} | m_t) p(E^*_{\ell-} | m_t)$$



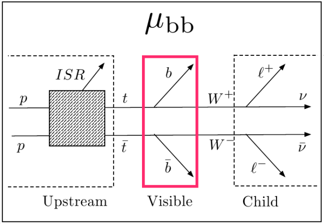
$$m_t = 172.50 \pm 0.4(\text{stat.}) \pm 1.5(\text{syst.})\,\text{GeV}$$

Kinematic Endpoints

CERN-PH-EP-2013-059



- New technique aiming at determining masses of particles in events of new physics (BSM).
- As in many SUSY signals, top dacays in dilepton channel has 2 undetectable particles.
- $t\bar{t}$ is an ideal scenario to test it.
- This analysis does not rely on MC calibration.



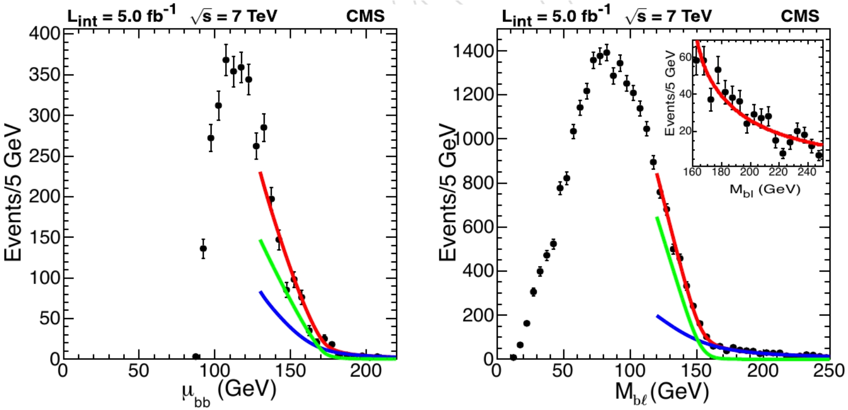
- Different systematics than the other measurements.
- Simultaneous fit of the endpoints (μ_{bb} and $M_{b\ell}$).

μ_{bb} lower bound of m_t for know m_W

$$M_{b\ell}^{max} = \frac{1}{m_W}\sqrt{(m_t^2 - m_W^2)(m_W^2 - m_\mu^2)}$$

Kinematic Endpoints CERN-PH-EP-2013-059

Double constrained fit (m_W and m_ν fixed), with: signal, background and full fit.



$$m_t = 173.9 \pm 0.9\ (\text{stat.})\ ^{+1.6}_{-2.0}(\text{syst.})\ \ \text{GeV}$$

Single lepton Channel

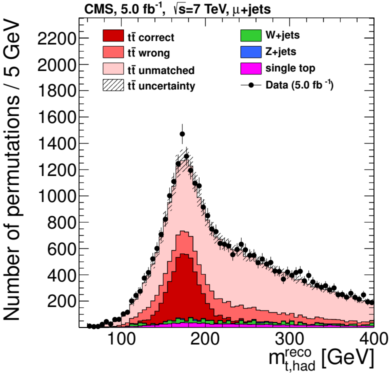
arXiv:1209.2319

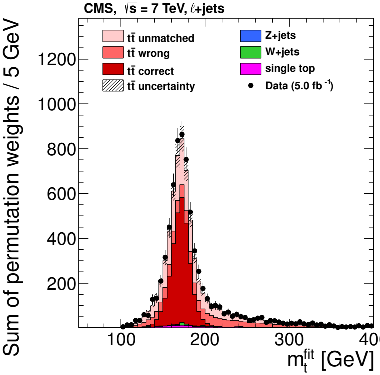
- Signal: μ or e with at least 4 jets.
- Main background: Single top.
- Top quark mass is determined simultaneously with the JES.

Ideogram Method

$$\mathcal{L}\left(\text{sample}|m_{\text{t}}, \text{JES}\right)_{evnt} = \sum_{i=1}^{n} c\, P_{\text{gof}}\left(i\right) P\left(m_{\text{t},i}^{\text{fit}}, m_{\text{W},i}^{\text{reco}}|m_{\text{t}}\ , \text{JES}\right)$$

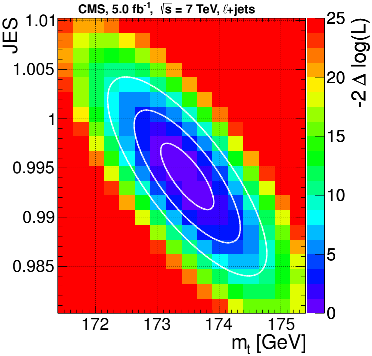
- The reconstructed W mass is used as an estimator *for measuring in-situ a residual JES*.





Single Lepton Channel

arXiv:1209.2319



- m_t obtained with simultaneous fit:

$$m_t = 173.49 \pm 0.43(\text{stat.} + \text{JES}) \pm 0.98(\text{syst.})\,\text{GeV}$$
$$\text{JES} = 0.994 \pm 0.003(\text{stat.}). \pm 0.008(\text{syst.})$$

- Fixing JES to unity:

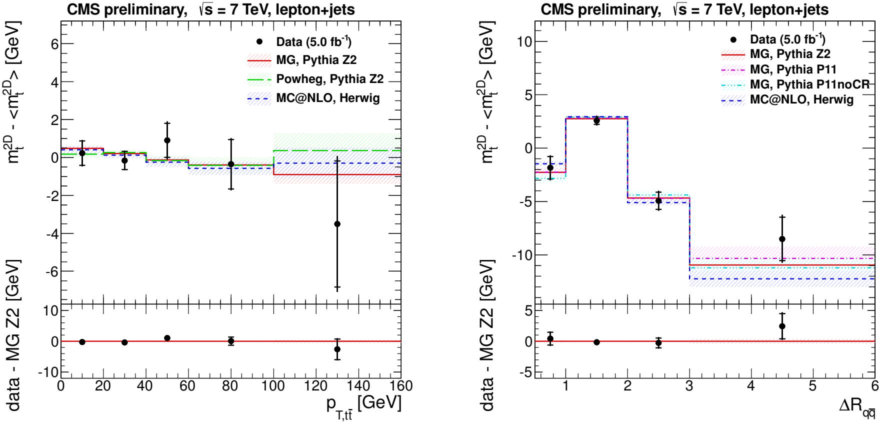
$$m_t = 172.97 \pm 0.27(\text{stat.}) \pm 1.44(\text{syst.})\,\text{GeV}$$

Simultaneous fit reduces the uncertainty!!!

m_t dependence on event kinematics: Single Lepton

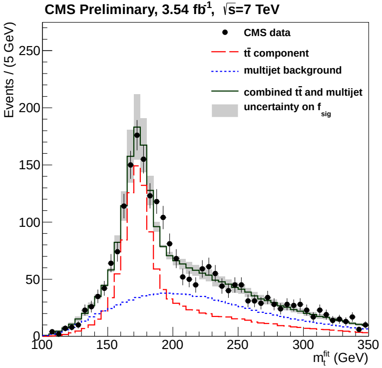
CMS PAS TOP-12-029

- Coloured top quark must connect to other partons through its decay products.
- For each bin, all permutations fulfilling the required kinematic properties are used.
- Focus in the effects of color connection, ISR/FSR and the sensitivity to the kinematics of the b-quarks.
- Kinematic dependence of reconstructed m(top) well described by MC.



Hadronic channel CMS PAS TOP-11-017

- Final state with at least 6 jets (2 b-tagged jets).
- Dedicated trigger and tight selection criteria ($b\bar{b}$ distance).
- Kinematic Fit
  1. Constrained: Mass of the two top quarks and $m_W = 80.4\,\mathrm{GeV}$
  2. Goodness of fit probability (P_{gof}).
- Background Modeling: event mixing technique.
- Ideogram method. Similar to single lepton analysis.
- Better precision in 1-D (fixing $JES = 1.0$) than 2-D fit??.



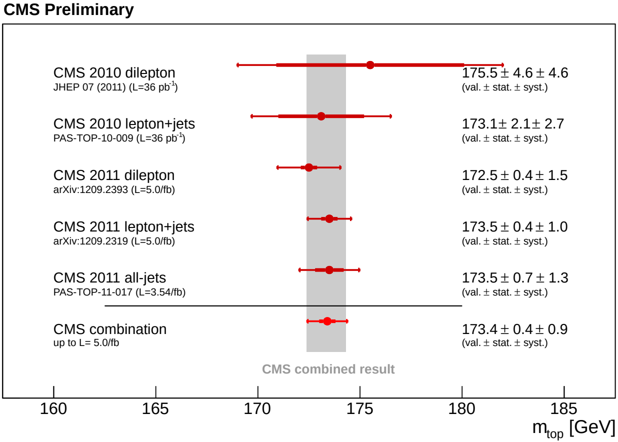
$$m_t = 173.49 \pm 0.69(\mathrm{stat.}) \pm 1.25(\mathrm{syst.})\ \mathrm{GeV}$$

Systematic Uncertainties: Global View

	Dileptons 2010	Lepton+jets 2010	Dileptons 2011	Lepton+jets 2011	All jets 2011
Measured m_t	175.50	173.10	172.50	173.49	173.49
JES	4.0	2.3	1.2	0.75	1.1
Lepton energy scale	0.30	—	0.14	0.02	—
MC generator	0.50	—	0.04	—	—
ISR/FSR	0.20	0.20	—	—	—
PDF	0.50	0.10	0.09	0.07	0.06
Factorization scale	0.60	1.10	0.55	0.24	0.22
ME-PS matching threshold	0.70	0.40	0.19	0.18	0.24
Signal					
Jet energy resolution	0.50	0.10	0.14	0.23	0.15
b-tagging	0.40	0.10	0.09	0.12	0.06
MET scale	0.10	0.40	0.12	0.06	—
Detector Modeling					
Underlying event	1.30	0.20	0.05	0.15	0.32
Background MC	0.10	0.20	0.05	0.13	—
Background Data	—	0.40	—	—	0.20
Fit calibration and MC	0.20	0.10	0.40	0.06	0.13
Pile-up	1.00	0.10	0.11	0.07	0.06
Color reconnection	n/e	n/e	0.13	0.54	0.15
Trigger	—	—	—	—	0.24
Total Systematic Uncertainty	4.52	2.63	1.41	1.03	1.25

Combination
CMS PAS TOP-11-018

- Best Linear Unbiased Estimator Method (BLUE).
- Different decay channels are non-overlapping by design: Uncorrelated statistical uncertainties

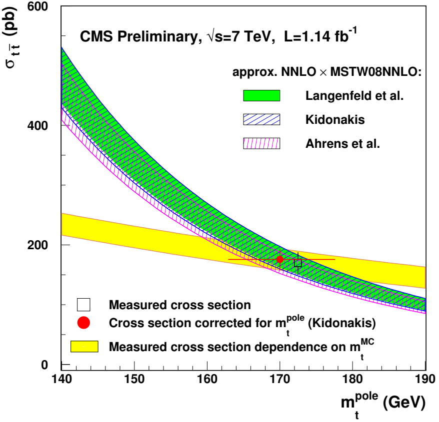


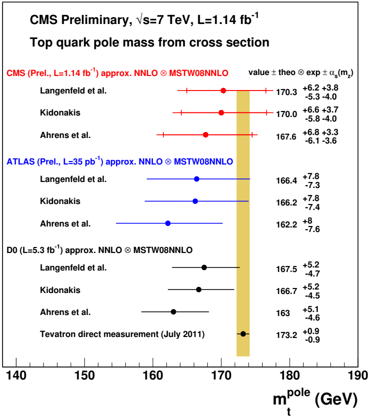
$$m_t = 173.36 \pm 0.38(\text{stat.}) \pm 0.91(\text{syst.})\ \text{GeV}$$

m_t from the $t\bar{t}$ cross section

CMS PAS TOP-11-008

- Exact top quark mass definition depends on choice renormalization scheme.
- Experimental dependence of top cross section measurement on assumed top mass (m_t^{MC}) is taken into account.
- m_t is extracted from the comparison between the $\sigma_{t\bar{t}}$ and calculations at high-order QCD.
- The aim of this analysis is provide a direct way to extract the mass from a given scheme.

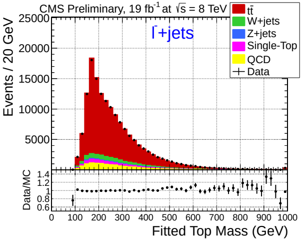


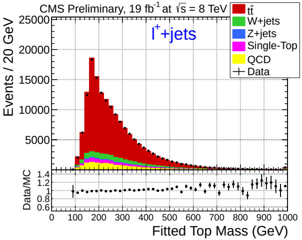


Top-antitop mass difference

CMS PAS TOP-12-031

- Single lepton + Jets channel at 8 TeV.
- The SM invariance under CPT transformation predicts $m_t = m_{\bar{t}}$
- Data are split into ℓ^+ and ℓ^-.
- Similar kinematic fit and ideogram method as in previous analysis.





Source	(MeV)
Jet energy scale	**17** ± 15
Jet energy resolution	8 ± **11**
b vs. $\overline{\mathrm{b}}$ jet response	**64** ± 7
Signal fraction	**45** ± 2
Bkg charge asymmetry	**12.43** ± 0.03
Bkg composition	**50** ± 1
Pileup	**17.4** ± 0.4
b-tagging efficiency	**20** ± 8
b vs. $\overline{\mathrm{b}}$ tagging efficiency	**43** ± 6
Method calibration	15 ± **54**
PDF	**12** ± 3
Total	122

Δm_t by channel:

$$\Delta m_t^{\mu} = -230 \pm 264(\text{stat.})\,\text{MeV}$$
$$\Delta m_t^{e} = -325 \pm 294(\text{stat.})\,\text{MeV}$$

Combined:

$$\Delta m_t = -272 \pm 196(\text{stat.}) \pm 122(\text{syst.})\,\text{MeV}$$

Some of the systematics effects cancel out:

- Modeling of Hadronization.
- ISR/FSR
- factorization and renormalization scales.

Summary

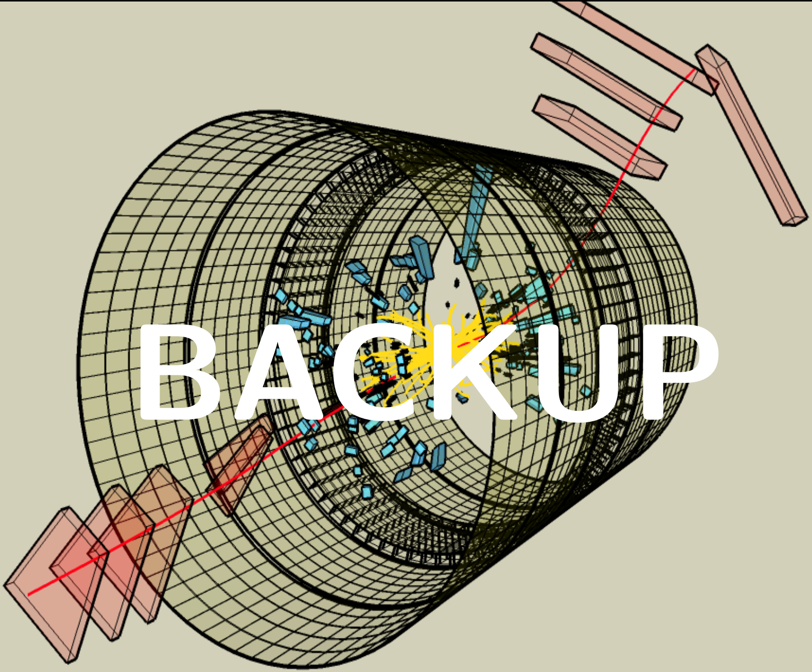
- CMS precision measurements of the top quark mass:

$$\boxed{m_t = 173.36 \pm 0.38(\text{stat.}) \pm 0.91(\text{syst.})\,\text{GeV}}$$

- The single most precise measurement is obtained in the $\ell + \textit{Jets}$ channel.
- CMS pursues a comprehensive program of top quark mass analyses with complementary systematics.
  1. several techniques to extract the top quark mass.
  2. studies of colour reconnection models and kinematic dependencies.
- Updates of the m_t measurement with all 8 TeV data are underway!

For more top quark results from the CMS detector:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP



BACKUP

Dilepton Channel

Full Kinematic Analysis (KINb)

- Jet P_T, MET direction and $P_z^{t\bar{t}}$ are varied to scan the kinematic phase space.
- The lowest invariant mass solution is taken if $m_t = m_{\bar{t}}$ in a $3\,\mathrm{GeV}$ window.
- An unbinned likelihood method is performed separately for same and opposite lepton flavour.
- Poorer mass resolution than AMWT...... This method is used as a cross check!